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Air emissions from ships in port: does regulation make a difference?

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Abstract
Vessel operations at port play a particular role in port-related air emissions. Hotelling, manoeuvring and cruising operations in the harbour areas generate a large share of local and global pollution, external costs and public health issues. Emission abatement demands effective regulation for vessel compliance and enforcement adequacy in despite of geographic differences in jurisdiction. A connecting relation between regulatory frameworks and atmospheric pollution from vessels operations at port is so far, missing in literature. This paper aims at filling in this gap by addressing exhaust gasses (NOx, SOx, CO, CO_2) and particles ($PM_{2.5}$) released from operative vessels in port with differing regulatory frameworks (Las Palmas, St. Petersburg, and Hong Kong). Estimations are based on the Ship Traffic Emission Assessment Model (STEAM) and AIS traffic information over a twelve-month timeframe. Contribution of this paper relates to revealing emission patterns of vessel operations in port and the assessment of current regulatory frameworks. Results and lower emission profiles shed light to sulphur regulation differences and the potential benefits in new policy measures (polluter pays principle, cold ironing and others) of accounting operative modes and shipping sub-sectors.

Keywords: Air emissions, Automatic Identification System (AIS), Port-Cities, Regulation.

1. INTRODUCTION

Shipping contributes to coastal emissions and pollution concentration subsequently adverted over land, increasing exposure levels to hazardous substances on residents and visitors (Tzannatos, 2010a; Miola, 2010; Castells et al., 2014; Tichavska and Tovar, 2015a). This mainly results from berthing[1] (hotelling), manoeuvring and cruising operative modes of vessels while at port (Goldsworthy and Goldsworthy, 2015).

Operative type and time varies on each harbour and this results into emission share differences. Indeed, in the case of some harbours, emission shares of cruising vessels (when approaching the berthing area) can be higher than those related to berthing operations (i.e. Tichavska and Tovar, 2015a). Also, time spent at berth is commonly higher when compared to cruising time to harbour and, this may also result in a large contribution to air pollution. Particularly, if vessels use diesel generators to cover their electricity needs. In addition to this, berths are often located near populated areas so the impact of emissions may largely result in local effects than those emissions released at open sea. From the three operative types, and although also generating an impact to local (due to the proximity to land) and global air quality, manoeuvring operations are identified as the least hazardous. The latter, due to the short duration of the manoeuvring phase (Goldsworthy and Goldsworthy, 2015).

A better understanding on emission pattern variation (while in hotelling, manoeuvring and cruising) should be stressed in port studies. This, with the two-fold aim of first, achieving a better understanding on operative vessel type energy demand and emission share differences to then motivate and support policy abatement measures. For instance, and when compared to cargo vessels, the energy demand (and emissions) from passenger vessels in harbour is commonly higher due to a different type of operative patterns (a continuous auxiliary engine usage while at berth).

The International Maritime Organization (IMO) has addressed ship pollution under the MARPOL convention and required a gradual decrease of NOx, SOx and PM from marine engines. Also, energy efficiency improvements for ships have been agreed through the introduction of the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP). Current regulation aims to reduce emissions from ships through the introduction of a minimum content of sulphur on fuel and the implementation of new abatement technologies.

The regulation of air pollution by ships was defined in MARPOL Annex VI, first adopted in 1997 and revised in 2008, including a progressive reduction of SOx and NOx and indirectly Particulate Matter (PM) in Emission Control Areas (ECA). MARPOL Annex VI is the only global regime that addresses the control of air emissions from ships in a comprehensive manner. At a global level, the IMO has so far not enforced a special regulation towards reducing vessel type-specific emission shares. Therefore, vessels should follow general regulatory guidelines (Cullinane and Cullinane, 2013).

In addition to this, and under the IMO regulations framework, MARPOL Annex VI sets a maximum 0.1% sulphur for all ship operations in Emission Control Areas (ECAs), including EU-territories such as the Baltic Sea, the English Channel and the North Sea.

[1] Berthing time is also known as hotelling time. This, since at berth most power requirements are related to on-board “hotel services”. Berthing or hotelling time begins when a ship ties-up at a berth and ends when it leaves that berth (Tzannatos, 2010).

The EU has expressed its willingness to unilaterally widen the enforcement of MARPOL Annex VI sulphur restrictions to all European seas. Nevertheless, this might face compliance constraints in relation to the United Nations Convention on the Law of the Sea 1982 (UNCLOS) to which the EU is signatory.

Moreover, and in the case of European waters, the European Union (EU) has expressed concerns about the impact of maritime transport on air quality through the Strategy for Sustainable Development published on its White Paper on Transport Policy (Kommission Europäische Gemeinschaften, 2001). This has led to the establishment of stringent sulphur regulation for marine fuels (directives: 2012/33/EU, 2005/33 and 1999/32). Indeed, and according to directives in force, all vessels calling at an EU port should either use low sulphur fuel (less than 0.1%) or a shore-side electricity facility during port stays longer than two hours. Also, all passenger ships operating on scheduled services to or from any EU port should not exceed 1.5% sulphur fuel limit.

Emission abatement demands effective regulation for vessel compliance and enforcement adequacy in despite of geographic differences in jurisdiction. A connecting relation between regulatory frameworks and atmospheric pollution from vessels operations at port is so far, missing in literature. This paper aims at filling in this gap by addressing exhaust gasses (NOx, SOx, CO, CO_2) and particles ($PM_{2.5}$) released from operative vessels in port with differing regulatory frameworks (Las Palmas, St. Petersburg, and Hong Kong). Twelve-moth vessel emission estimations are based on the Ship Traffic Emission Assessment Model (STEAM) which calculates emission totals, among others, based on an updated database of vessel particulars and parameters previously omitted in literature (engine load and speed). These are obtained from vessel tracks transmitted by the Automatic Identification System (AIS)[2] and received via terrestrial AIS stations over a period of twelve months.

To the best of our knowledge, the present study is the first one to account the estimation of vessel emissions in harbour areas under diverse geographical and regulatory frameworks. The selection of ports was based on their common attribute as regional cargo and passenger hubs with increasing cruise and ferry services in EU (Las Palmas), non-EU and SECA (St. Petersburg) and non-EU non-SECA harbour areas (Hong Kong). Results enable a comprehensive assessment on emissions patterns from cargo and passenger vessel traffic. The latter results into a first approximation to emission profiles (of ports and vessels) and its relation to the fuel sulphur content regulation in force over the period under study. Moreover, the estimated results represent a baseline externality scenario to address future measures that reduce the local and global impacts of vessel emissions.

The structure of this document is described below. After the introduction, Section 2 describes the study areas and its port traffic and regulatory (SOx) profiles; Section 3 includes a brief literature survey on the calculation of vessel emissions and the description of the methodology and model used. Section 4 presents results. To finalize, Section 5 displays discussion and policy recommendations.

[2] Terrestrial and Satellite AIS signals are limited by geographical and temporal coverage. Nevertheless, in the present research, the range of terrestrial receivers cover the study areas in question. Temporary data gaps may exist because of network failure in data reception, but long periods with no data were not observed in this study. Further, the STEAM has an interpolation algorithm which can mitigate intermittent gaps in AIS data. With this approach, results do not change whether AIS data was received with full update rate or down sampled to a few position updates each hour. For additional details, the reader is referred to Section 3.2

2. STUDY AREAS

Ports constitute maritime transport nodes where all shipping routes ultimately converge. Ship operators seek for well-located and connected ports, commonly located near industrial and populated areas (Castells et al, 2014). Port-cities are exposed to vessel emissions and environmental, health and infrastructure burden.

The design of an effective regulatory framework for the improvement of air quality, requires of more accurate information on how much, where, how and who releases emissions. For this, not only an accurate calculation of emissions from vessel movements (position, speed, technical configuration and operative type[3]) is required but the disaggregation of results should also be addressed (ship categories and sub-categories)[4]. For this reason, and by using the STEAM (see Section 3.2) this paper calculates and describes general traffic (cargo, container, tanker, passenger, other) and passenger traffic (cruise and ferry) vessel emission results. Also, results by size and month have been included.

Study areas include ports with sulphur legislation differences. Namely, Las Palmas, as a EU port outside a SECA, St. Petersburg as a SECA port, and Hong Kong as a port only subject to IMO regulation and a voluntary low sulphur program. Moreover, and since destinations with a high volume of passenger traffic (cruise and ferry) are highly sensitive to air pollution (Dragovic, et al 2015), our selected ports are also characterised for a traffic significance as hubs for ferry and international cruise activity.

Indeed, recent literature motivates a more comprehensive valuation of passenger vessel emissions (Tzannatos, 2010ab; Poplawski et al., 2011; Soares et al., 2014; Maragkogianni and Papaefthimiou, 2016; Tichavska and Tovar, 2015ab and Dragovic, 2015). The latter, due to the increasing operation and potential burden (health, infrastructure and environment) of cruise service operations in major harbours (well-located and connected), densely populated and attractive locations. Similarly, emissions released by ferry services raise concern due to the frequent and busy short-distance itineraries operating across channels, straits and archipelagos. In addition to vessel emission inventories and the assessment of green policy and abatement alternatives (scrubbers and shore-side electricity), recent literature sheds light into quay emission hot spots dedicated to cruise and ferry operations (Tichavska and Tovar, 2015a). Within this line, and with the analysis of cruise and ferry emissions, this study motivates a similar assessment. This is of particular interest since no special regulation has been yet designed for these sub-sectors and effective measures could significantly reduce the overall vessel emission harbour quota. With the aim of introducing the study areas in this research, sub-sections

[3]Undoubtedly, the dimensions, speed and technical configuration of operative ships varies and this affects their emissions profile in harbour. For instance, and during port visits, auxiliary engines are used to generate electricity while main engines do not contribute to fuel consumption and derived emissions significantly. Particularly during hotelling (Jalkanen et al., 2009).

[4] Cargo transportation by sea has been traditionally categorised into general merchandise (conventional and container) and bulk (liquids and dry bulk or solids). This has influenced not only the design and performance of ships, based on the type of cargo they are transporting, but also the organization the industry. Bulk shipping (tankers and dry bulk), for instance, have no fixed route and schedule as these are commonly used to transport homogeneous cargoes as commodities and raw materials. Conversely, general merchandise is carried by liner services, mainly in containers and, within regular trade routes and port visits. Moreover, passenger shipping distinguishes services oriented to a recreational segment (cruise) and a short-sea shipping transportation segment carrying passengers and sometimes vehicles and cargo across bodies of water (ferry). All, with inherent operative particularities.

2.1, 2.2, 2.3 and 2.4 briefly present characteristics, traffic and regulatory (SOx) profiles of each port.

2.1 Las Palmas

Located in the Atlantic Ocean, Las Palmas Port is the fourth largest within the Spanish port system (Tovar and Wall, 2012). Also it is a major logistic platform between Europe, Africa and America. Its location between main commercial trade routes makes it a cargo hub and also a leading worldwide bunker trader (see Table 1 below). In addition to the regular ferry services to meet the regional transportation demand, passenger numbers accounted in cruise operations in the Canary Islands steadily increase (EDEI, 2011).

Arrivals and departures from Las Palmas Port by ferry or cruise occur according to regular schedules. While port calls of cruise vessels occur in a weekly basis, ferry services to other Canary Islands are offered daily. Santa Catalina passenger quays in Las Palmas Port are located in the city centre and have remained until recently as the main hub for base operations of cruise and ferry services. Santa Catalina passenger quays enable an easy access to shopping centres, local and regional bus services and city beaches.

Starting 2012, ferry routes have been relocated to quays in the forthcoming passenger terminal La Esfinge (first stage completed in 2015, and second stage in 2016). With a new area of over 40,000 square meters ferry services will be centralized in Nelson Mandela quay. Cruise traffic has been kept in Santa Catalina where Las Palmas Port invested resources with the aim to increase its capacity as a transatlantic cruise port. The port can take the world`s largest cruise ship and starting 2015, it can service up to five cruise vessels and over one million cruise passengers per year.

2.2 St. Petersburg

The city of St. Petersburg, located in the eastern part of the Gulf of Finland, comprises of several port areas (Seaport of St. Petersburg, Primorsk, Ust-Luga, Vyborg, Vysotsk and the passenger port of St. Petersburg) in North-West Russia. The ports of St. Petersburg are multipurpose ports that have both cargo and passenger operations (see Table 1 below). Navigation occurs all year round; although in winter, traffic is limited by ice navigation restrictions and pilotage performed by icebreakers. The ports of St. Petersburg are large according to the Baltic standards; however, in the global scale they are relatively small. In terms of cargo structure, containers have a minor role, whereas dry cargo, bulk, and especially liquid bulk prevail. Serving as an import port for nuclear waste, St. Petersburg has a large turnover of hazardous substances and chemicals, which raises environmental risks.

Since 1996, there has been a steady increase in the number of cruise ships and passengers visiting St. Petersburg. Cruise shipping is important for the city´s economy. The St. Petersburg area includes five harbours serving passenger traffic. The main of the St. Petersburg passenger ports today is the Marine Façade. The port can take a cruise and ferry vessels up to 330 meters' length and up to 8.8 m draft. According to the Committee on Investments and Strategic Projects of St. Petersburg Administration, in 2011 about 600 000 tourists arrived to St. Petersburg by sea, including 456,000 cruise passengers and almost 170,000 ferry passengers.

2.3 Hong Kong

Strategically located on the Far East trade routes and at the centre of the fast-developing Asia Pacific Basin has gradually developed over the years into a world-class container, transshipment and passenger hub in the South East and East Asia region (see Table 1 below).

The port of Hong Kong is the second busiest container port in the world. Its layout includes nine container terminals which occupy 2.17 square kilometres of land. This comprehends 18 berths and 6,592 metres deep water frontage. Also a total handling capacity of over 18 million twenty-foot equivalent units (TEU) and 11 different yard sites solely for mid-stream[5] operations. This occupies a total land area of 27.5 hectares and water frontage of 3,197 metres. Moreover, the River Trade Terminal involves the consolidation of containers, break bulk and bulk cargo shipped between the Hong Kong port and ports in the Pearl River Delta

In terms of regional passenger services, the Hong Kong-Macau Ferry terminal in Sheung Wan and the China Ferry Terminal in Tsim Sha Tsui provide centralised routes to Macao and 11 ports in the mainland in frequent services with a time interval of 30 minutes approximately. The fleet navigating these terminals is mostly comprised by high-speed passenger crafts such as jetfoils and catamarans. Regarding cruise services, the continuance of the maritime leadership of the city, including the cruise sector, has been one of the most important objectives of the Hong Kong government since 1995 and thereafter consistently claims the necessity to build new cruise facilities (Lau et al., 2014). According to the Kai Tak Cruise Terminal has been built to accommodate two large 360-metre-long 100,000-tonne-class vessels, disembarking a total of 5400 passengers and 1200 crew members at the same time.

2.4 Port Traffic and Regulatory (SOx) Profiles

Table 1 shows the traffic profiles of the three harbours under study which are based on available statistics regularly published by public authorities and ports. In its first column it identifies the name of the port and year under study. This is followed by the tons carried by tankers, general cargo, container (the latter in tons and TEU), other vessels and the registered arrival of passengers (cruise and ferry). Also, and to have a better understanding of the activity level of each port, Table 1 includes the number of calls to port based on AIS details broadcasted by individual vessels (in the form of port of origin/port of destination). At last, it summarizes SOx regulation.

Table 1 – Traffic profiles of the three harbours under study

	Tanker	General Cargo	Container	Container	Rest	Ferry	Cruise	Port calls (AIS)	SOx Regulation
Port	**000 ton**	**000 ton**	**000 ton**	**TEUs**	**000 ton**	**Pax**	**Pax**	**Number**	**Regulatory framework**
LP (2011)	3,188	2,393	13,766	1,285,586	5,214	798,771	427,592	16,537	EU
STP (2011)	15,739	13,963	21,978	2,365,174	8,309	122,000	405,000	11,484	non-EU and SECA
HK (2012)	17,721	12,029	203,964	23,117,000	35,569	26,000,000	1,382,296	22,877	non-EU and non-SECA

Source: Own elaboration based on available port traffic statistics and AIS-based port calls.

Port traffic profiles presented in Table 1 reflect that the ports selected in this paper are characterised by a traffic significance not only as cargo hubs but also as hubs for ferry and international cruise activity. In terms of SOx regulation, Las Palmas Port (EU port)

[5] Mid-stream operation involves loading and unloading containers to and from ships while at sea, with barges or dumb steel lighters performing the transfer, and then distributing or landing the containers to piers nearby.

falls under the jurisdiction of the EU Sulphur Directive 2005/33/EC provisions, which entered into force since the 1st of January in 2010. This limits fuel sulphur content to 0.1% in vessels anchored at EU ports and 1.5% in passenger vessels operating on regular services to EU Ports. So far, Canarian ports have not installed shore side electric power for ships[6]. Moreover, and although the utilization of LNG for powering island ferries is addressed in literature as a promising alternative to oil-fuel (Tzannatos et al, 2015); this had never been approached in Las Palmas until the present year (2016) as Las Palmas Port Authority begins the process to the offering of this service. In despite of this, its forthcoming passenger terminal (to be completed in 2016) is expected to allow significant cost and fuel savings by centralizing routes linking other Canary Islands and the Spanish mainland. These measures foresee to save at least 20 minutes of travel within regional and national sea routes, also reducing fuel consumption and, therefore emissions. Moreover, the relocation of ferry services away from densely populated areas (starting in 2012) may not only result in operative improvements but in a positive contribution to air quality in the port-city (Tichavska and Tovar, 2015a).

St. Petersburg does not fall under the scope of EU regulation, but is situated in the Baltic SECA under MARPOL Annex VI, which limited the sulphur content in fuel to a max. 1% since the 1.7.2010 and starting the 1.1.2015 to a max. of 0.10%. On the other hand, annual program of environmental activities in the Port of St. Petersburg is formed on the basis of international, federal and provincial regulations in the field of environmental protection led by the State Unitary Enterprise “Rosmorport” of the North-West Basin Branch "Rosmorport". Standards for emissions of pollutants into the air are defined in accordance with federal legislation and fix-term pollution certificates are acquired from the Department of the Federal Service for Supervision of Natural Resources. Finally, there is no available shore-side electricity in “Marine Façade” the time being. Yet, the issues of air emissions from ships are being discussed and a revised methodology to calculate ship emissions in St. Petersburg has been recently introduced (Krylov et al., 2012).

The port of Hong Kong does not belong to special areas designated by MARPOL Annex VI nor follows EU regulation but is affected by the global regulation of a maximum applicable sulphur cap of 3.5% started on the 1st of January in 2012. Moreover, starting on the 1st of July 2015 Hong Kong mandatory low sulphur regulations became effective. The Regulation requires all ocean-going vessels (above 500 GRT) to switch to low-sulphur fuel (or LNG/or similar approved fuels) during the periods the ship is at a berth, excluding the first and last hour of the berthing period. The sulphur content of the fuel may not exceed 0.5%. The new regulations are expected to reduce SOx emissions by a 12% and PM by a 6%. At last, and as a precedent of voluntary measures, since 2013 a pact for the use of cleaner fuel in Hong Kong has been agreed by shipping companies registered in the Hong Kong Liner Shipping Association (HKLSA). To the knowledge of the authors no details on the actions are publicly available or easily accessed.

[6] Nevertheless, the Port Authority of Las Palmas Port is participant partner in the EC funded project Master Plan for OPS in Spanish Ports (Agreement No. INEA/CEF/TRAN/M2015/1128893), led by the Public State Ports Body. Project aims to design and implement a series of actions on docks and ships to supply electricity on shore and within the Spanish port constellation. Also and in collaboration with partner shipping companies and Port Authorities, pilot tests have been envisaged in Palma de Mallorca, Tenerife and Las Palmas.

3. THE EMISSION OF EXHAUST POLLUTANTS FROM SEAGOING VESSELS

3.1. BRIEF LITERATURE SURVEY

Over time, the calculation and the geographical characterization of vessel emissions have been addressed over shipping and port studies. For this, bottom-up and top-down methodological approaches have been used. A bottom-up approach involves calculations based of fleet activity (port calls and estimated vessel operative or vessel tracks and real time vessel operative) while a top-down approach is based on combining marine bunker fuel statistics and technology based emission factors. Regarding the geographical characterization of results and the level of details achieved, differences rely on the approach followed (bottom-up and top-down). Within these, a bottom-up approach is based on individual vessel positions (granular traffic details) while a top-down approach is based on non-granular and partial information. For instance, based on one / few shipping routes or, an activity GIS raster cell. Finally, a full bottom-up approach is defined by Miola et al., (2010) as the use of bottom-up approached in both emission calculation and the geographical characterisation of results.

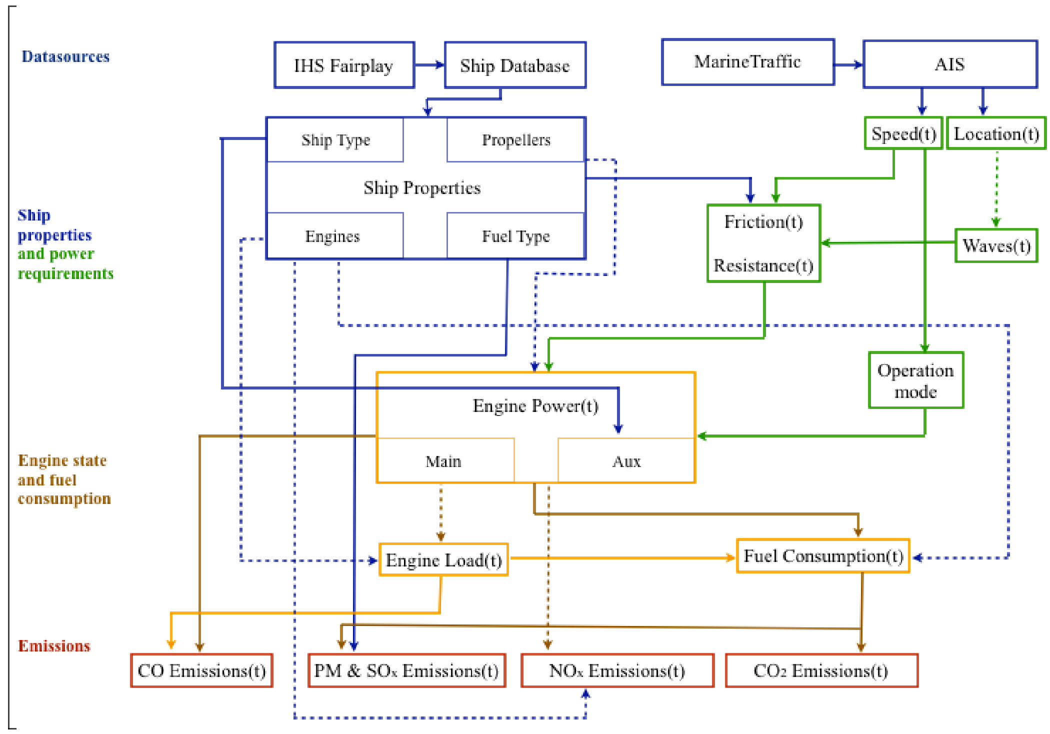
Limited information and methodological assumptions in literature results in an open debate on the adequacy of each approach in the study contexts (port and region) undertaken so far (Miola et al., 2010). In this same line, Buhaug et al., (2009) compares differences and uncertainties from available maritime studies. The detailed activity-based modelling is widely considered as the best practice approach for the creation of local (harbour) and regional inventories although the latter and wider study scopes experience the challenge of non-available granular details. The need and benefits of more accurate and disaggregated calculations motivate the use of granular traffic details and the so called full bottom-up approach. This may guarantee that, for instance, individual vessels´ radio-transmitted location, speed, route, dimensions and particulars (i.e. individual technical configuration) are accounted and represented in emission totals. For additional details on full bottom-up methodological approaches and its use to calculate environmental port efficiency indicators, the reader is referred to Jalkanen et al., (2009, 2012), Goldsworthy and Goldsworthy, (2015), Song, (2014) and Tichavska and Tovar, (2015ab).

For an overall assessment of available vessel emission studies, the reader is referred to global studies by Corbett and Fischerbeck, (1997); Corbett and Fischerbeck, (1999), Skjølsvik, et al., (2000); Endersen et al., (2007); Paxian, (2010); Buhaug et al., (2009) and (Smith et al., 2015). Also to regional studies undertaken by Wang et al., (2007); Jalkanen et al., (2009), Howitt et al., (2010); Pitana et al., (2010); Goldsworthy and Galbally, (2011), Johansson et al., (2013); Jalkanen et al., (2016); Li et al., (2016) and Cullinane et al., (2016). At last to local (harbor) studies in Miola et al., (2010) and recent studies such as Ng et al., (2012), and Tichavska and Tovar (2015a). A review of other vessel emission inventories within the scope of externality cost port studies may be assessed in Tichavska and Tovar (2016).

3.2 METHODOLOGY

Based on a recent review of the methodological and empirical state of the art (see Tichavska, 2015), the Ship Traffic Emission Assessment Model (STEAM) by Jalkanen et al. (2009; 2012) has been selected and used to calculate the tons of gases and particles released by vessels in port. Model components are presented in Figure 1. Input data and output results are shown in the uppermost and lowest row of the figure. Arrows reflect the information flow within the model and dependency between factors. Additionally, dotted and solid arrows are used for visual clarity. Colours denote variable categories included in the model.

Figure 1 – Main components of the STEAM model and their inter-relations



Source: adapted from Jalkanen et al. (2012).

The model used terrestrial AIS[7] data as input information from a 12-month period Vessel tracks from the ports of Las Palmas (2011), St. Petersburg (2011) and Hong Kong (2012)[8] were obtained from MarineTraffic to be used in the model. AIS movement information is exclusively included in the estimations when the average speed between two vessel position reports is reasonable with the distance and time of navigation reported. Furthermore, no emissions are estimated for data gaps, which exceed a period of 72 h.

The STEAM takes into consideration the speed of the vessel, its operative modes and technical characteristics of the vessels[9] in order to estimate engine power[10] and fuel consumption at frequent intervals. More specifically, main engine power is calculated using ship speed, hull resistance and propeller efficiency. Alternatively, and if no sufficient data on a vessel is available, the main engine power is assigned from a closest matching vessel in the internal ship database. The real time effect of waves on the main engine power can be estimated, but the added resistance because of waves was neglected in this study. Auxiliary engine power is set up to be dependent on the operation mode, partially dependent on the ship type and independent of the ship size. A power

[7] The AIS is a mandatory collision avoidance system installed on ships. Each vessel transmits a signal including details on speed and location at frequent intervals. Numerous ground stations located at ports and on the coast record information transmitted by the AIS. This is known as terrestrial AIS data.
[8] In the case of Hong Kong terrestrial AIS was exclusively available from 2012 onwards and thus has been selected to reflect a similar period in time than the rest of harbours in this study.
[9] The technical configuration of vessels that relate to main and auxiliary engines, auxiliary boiler, and the abatement technologies installed are obtained from an internal database within the STEAM.
[10] The main engines of ships provide the propulsive power and consume the most fuel when at sea while auxiliary engines run while vessels are at sea and also at berth. Electricity, generated by the auxiliary engines, is used for lighting, cooking, air conditioning, heating, pumps, auxiliary blowers, bow thrusters, control systems, cargo handling and others. The power usage depends on the operating mode.

consumption allowance is made for the number of cabins subject to air conditioning on passenger vessels and the refrigerated cargo capacity on container vessels.

Summarizing, exhaust emissions obtained from STEAM are calculated by considering emission factors for the particular vessel type, size, technical characteristics, and operative mode (hotelling, manoeuvring and cruising) of the vessels. These and are mainly based on the AIS and ship database built within the STEAM. Moreover, the STEAM assumes compliance to the sulphur regulation in force within the areas and timeframes under study.

Particularly, and in the harbour area of Las Palmas (EU regulation) a 0.1% sulphur content is assumed from all berthing ships (that berth for more than 2 hours). Also, fuel sulphur content when manoeuvring and in transit is set up to a maximum of 2.7% for non-passenger vessels and to a 1.5% for passenger vessels. St. Petersburg is not subject to European Regulation but has been assigned as a SOx Emission Control Area (SECA) by the IMO. As such, the STEAM assumes the use of ship fuel that does not exceed a sulphur content of 0.1% while at berth. In the case of Hong Kong, a sulphur limit of 2.7% was used[11]. This, since in the year under study no binding low-sulphur content requirements on fuel had entered into force. Hong Kong area is subject to global fuel sulphur requirements (3.5%), but the average sulphur content is closer to 2.7%. However, in some cases and due to the engine specifications of vessels, the use of lower fuel sulphur content had to be accounted in the model (i.e. if the installed engine can not run on Heavy Fuel Oil).

Table 2 summarises fuel sulphur content used in the calculations. This includes regulatory frameworks and directives (as reference), followed by the fuel sulphur limits used (vessels berthing, manoeuvring and in transit).

Table 2 – Fuel sulphur content used in the modelled results

Ports	Regulatory Frameworks	Directive	Ships berthing for more than 2 hours		Manoeuvring and in transit	
			All vessels	Passenger vessels	All vessels	Passenger vessels
LP	EU	D.2005/33/EC (01/01/2010)	0.1	0.1	2.7	1.5
STP	NON EU SECA	SECA (01/07/2010)	0.1	0.1	1	1
HK	NON EU NON SECA	Marrpol Annex VI (01/01/2012)	2.7	2.7	2.7	2.7

The methodology used is consistent across all ports and results are obtained from two different model runs. The first one is based on vessel traffic in the three harbour areas (all ships and speeds included)[12]. The second one, is based on passenger vessel traffic (recorded speeds lower or equal to 5 knots). The motivation of including a speed limitation in the second model run is to allow a more refined comparison among ports (as

[11] Regulation in force for Hong Kong in 2012 (year under study) is 3.5%. Nevertheless, we use 2.7% as limit since during the modelled years (2011-2012) the HFO fuel sold globally had 2.7% or less sulfur. This is why 2.7% is commonly used for global shipping emission studies. The voluntary program which encourages the use of low sulphur fuel in Hong Kong area was not considered in this study, because no information of vessels participating in this program was available. According to the Hong Kong legislative panel roughly one third of the ocean going vessels participated in this program.

[12] See port area selection and fairway details in the Footnote 14.

results do not reflect fairway differences) and facilitate a more detailed analysis on hotelling (berthing) and manoeuvring operations. The emission contribution of vessels anchored in port (not in the berthing but in the port area) has been considered in the before mentioned model runs. Thus, hotelling (berthing) results should be used and interpreted with care[13].. Indeed, since berthing modelling method is based on vessel speed, we assume anchored ships are berthing. Moreover, and although anchored vessels have been included in the modelling, uncertainties related to the emissions of ships (particularly the 2h berthing rule) while being anchored exist.

4. RESULTS

Table 3 presents estimated tons of gases and particles (NOx, SOx, $PM_{2.5}$, CO and CO_2) released by vessels within the port areas[14] under study. It is noticeable that in all cases tons of NOx emissions are considerably higher when compared to the other pollutants which associate with local air quality impacts (NOx, SOx, $PM_{2.5}$, CO). Also, it can be observed that when comparing Las Palmas (EU) and St. Petersburg (SECA), the emission share of St. Petersburg is considerably higher in each of the measured pollutants with the exception of SOx and $PM_{2.5}$. Moreover, and despite of the minor level of activity reflected in the port calls, St. Petersburg has more than double the NOx and CO_2 emissions, but PM and CO emission totals are similar and SOx emissions are less than half when compared with results for Las Palmas (0.05 and 0.09 ton per port call, respectively). Results, although also affected by traffic shares and the configuration of the ports (such as differences in the fairway channel[15]), highlight the influence of a stringent SECA regulation affecting SOx and $PM_{2.5}$ when compared to sulphur framework in the EU. The later assumption is confirmed when observing results in the port of Hong Kong (Non-EU, non-SECA) where no sulphur regulation has been accounted and the tons of SOx per port call are more than nine and sixteen times the totals when compared to Las Palmas (EU) and St. Petersburg (SECA), respectively. The same occurs with $PM_{2.5}$ per port call which are again more than nine and six times higher than the rest of ports figures.

Table 3 – Total emissions in Tons for the three harbours under study

Port (year)	Area	NOx	SOx	$PM_{2.5}$	CO	CO_2	Port calls (AIS)
	Decimal coordinates	[Ton]	[Ton]	[Ton]	[Ton]	[Ton]	Number
LP (2011)	LAT from 28º to 28.4º, LON from -15.6 to -15º	4,237	1,420	338	497	208,697	16,537
STP (2011)	LAT from 59.8º to 59.9º, LON from 29.7º to 30.5º	8,665	575	345	577	480,000	11,484

[13] It would be desirable for hotelling/anchored operations to be differentiated. Particularly for policy purposes. Nevertheless, this will not be possible for this case study and thus has been only considered as a very valuable suggestion and future modelling methodology improvement. Fortunately, and in the case of passenger vessels in this study (model run #2, passenger vessels only, limited speed), the methodological approach followed and the special consideration of hotelling/manoeuvring operations does not represent a major problem in the passenger sector. This would exclusively be the case if a relevant congestion issue had been experienced at the ports (as it happens in Dragovic et al (2015), which is not the case here.

[14] In this study, the limits of the port areas were defined as described in Table 3. In terms of the fairway included in the calculations, this is a 40km fairway leading to the harbour in Las Palmas, a 30km fairway leading to the Port of St. Petersburg (area inside the Kronstadt island flood gates) and a 40km fairway in the case of Hong Kong (port area based on case study in Ng et al. 2012).

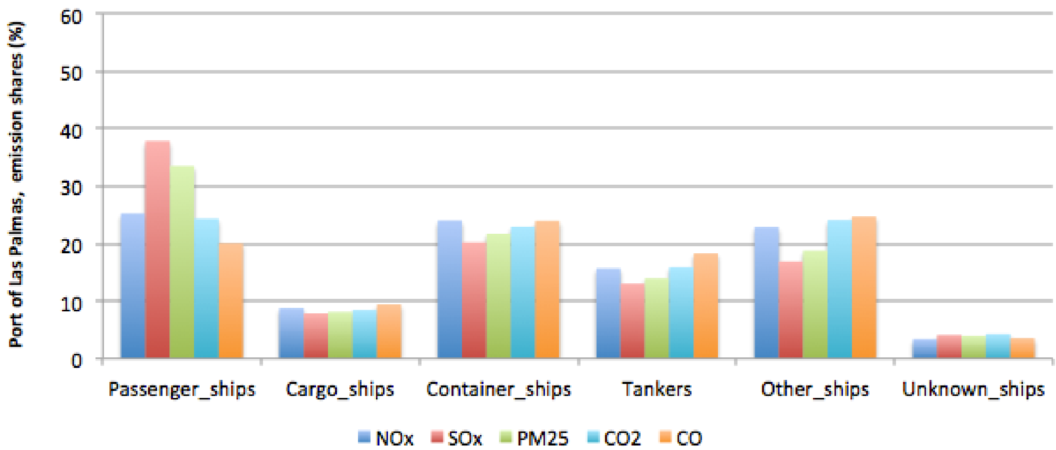
[15] See previous Footnote.

HK (2012)	LAT from 22.1º to 22.6º, LON from 113.8º to 114.5º	46,600	18,400	4,162	4.979	2,480,000	22,887

In order to improve the view and comparison of representative emission shares, emission totals per shipping categories are presented as a relative percentage from the harbour totals in Las Palmas (Figure 3) St. Petersburg (Figure 4) and Hong Kong (Figure 5).

In the port of Las Palmas (Figure 3) and in terms of pollutants, which relate to local externalities (NOx, SOx, $PM_{2.5}$ and CO), the role of passenger, container and other vessels are the most representative. Similarly, and in terms of gases which associate to global effects (CO_2) the highest shares derive from passenger, container and other vessels. Finally, and in terms of SOx, as the only pollutant directly addressed under emission control by limiting the maximum sulphur content of the fuel oils loaded, bunkered, and subsequently used onboard reflect (ordered from the largest to the smallest) a contribution of a 38% from the total share in the category of passenger; 20% in container, 17% in others, 13% in tankers, 8% in cargo and 4% in unknown[16].

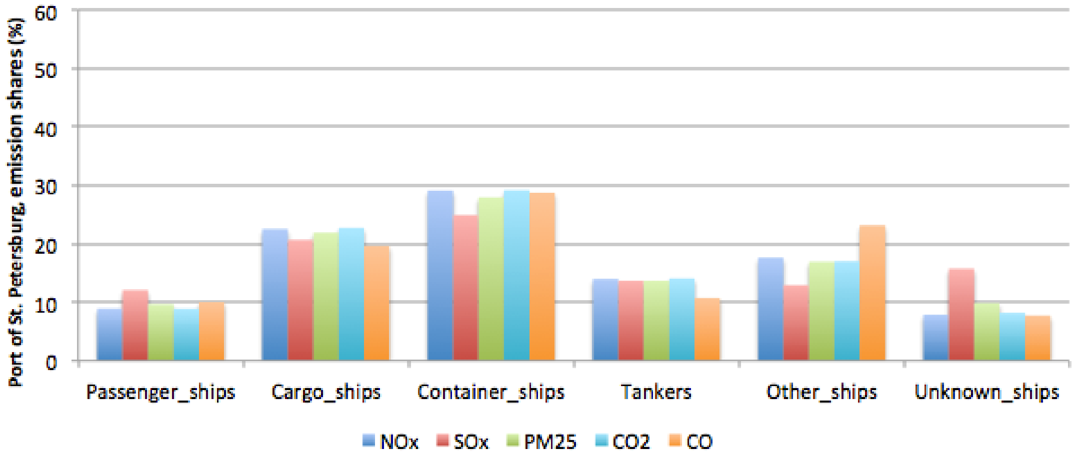
Figure 3 – Emission results by subsectors in Las Palmas Port (2011)



In St. Petersburg Port (Figure 4) and in terms of NOx, SOx, $PM_{2.5}$ and CO, the role of container and cargo vessels are considerably higher from the rest. Similarly, and in terms of CO_2, the highest shares derive from container and cargo vessels. Finally, SOx results reflect a contribution (ordered from the largest to the smallest) of a 25% from the container category, a 21% from cargo, a 16% from unknown, a 14% from tankers, a 13% from others, and a 12% from passenger vessels.

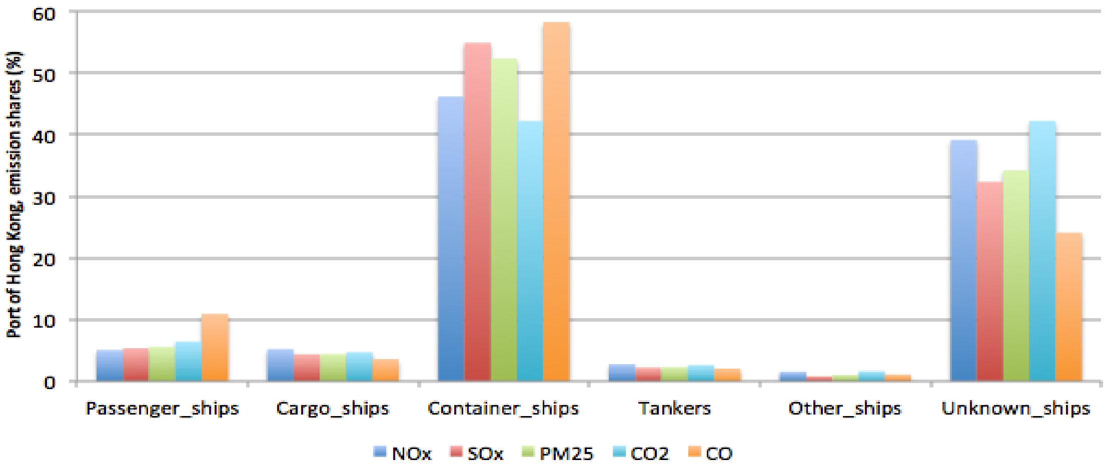
Figure 4 – Emission results by subsectors in the port of St. Petersburg (2011)

[16] Details on codes and category of vessels transmitted by the AIS are referred in the ITU-R, (2010). Unknown category refers to failure cases of identification (no static message received, no connection to national MMSI databases available, small vessels not transmitting a valid IMO registry number).



In the port of Hong Kong (Figure 5) and in terms NOx, SOx, $PM_{2.5}$ and CO, the role of container, and unknown vessels are most representative. Similarly, in terms of CO_2, the highest shares derive from container, unknown[17] and passenger vessels. Finally, SOx, results reflect a contribution (ordered from the largest to the smallest) of 55% from the container category, 16% form unknown, 5% from passenger vessels, 4% from cargo, 2% from tankers and 1% from others.

Figure 5 – Emission results by subsectors in the port of Hong Kong (2012)



In summary, emission profiles by sub-sectors in the three harbours reflect differences based on two visible reasons. The first one relates to sulphur regulation (lowest levels of SOx and $PM_{2.5}$ in Las Palmas and St. Petersburg) and the second to inherent the port configuration (layout and port specialization differences). For instance, Las Palmas Port, as a transhipment hub of cargo and also a hub of passenger services; St. Petersburg as a main gateway of cargo and container and Hong Kong as one of the busiest container ports translate in the largest shares of these vessel categories within their total sum of emissions. In line with the later and in terms of SOx and $PM_{2.5}$ passenger and container vessels in Las Palmas represent a 38% and a 20% respectively adding up more than half from the port totals. Also, in St. Petersburg shares of cargo and container vessels arrive to similar

[17] A substantial number of small (<300 GT) vessels exist, which are not required to use AIS. For such vessels the use of AIS is voluntary. If a vessel cannot be identified at all, it is assumed to be an unknown small craft. In the case of Hong Kong, and considering the recognized activity of government fleet, emission results associated to unknown vessels may be partly attributed to either small passenger crafts or, to vessels serving under government departments such as the Marine Police, Customs and Excise; and Fire Services.

numbers while in Hong Kong, container vessels represent the largest category with over a 50% from the total share.

Differences among results between sub-sectors may also be due to the combination of size classes within each group of vessels. Indeed, the size of vessels may be crucial when obtaining results of fuel consumption and derived emissions. To illustrate the latter point, emission results by Gross Tonnage (GT) size classes in Las Palmas Port, St. Petersburg and Hong Kong are presented as a percentage from the totals in harbour in Table 4.[18]

Table 4 – Emission results in percentage by vessel size class

	Port of Las Palmas					Port of St. Petersburg					Port of Hong Kong				
Size class	**NOx**	**SOx**	**$PM_{2.5}$**	**CO**	**CO_2**	**NOx**	**SOx**	**$PM_{2.5}$**	**CO**	**CO_2**	**NOx**	**SOx**	**$PM_{2.5}$**	**CO**	**CO_2**
< 4kt	21.14	15.79	17.32	24.92	23.81	36.79	40.84	37.14	28.84	36.82	45.86	38.49	40.8	36.03	50.42
4-10kt	20.41	14.26	16.28	20.61	20.56	22.84	19.23	22.74	23.76	23.3	3.01	2.29	2.45	2.19	2.9
10-20kt	21.63	28.55	26.04	17.47	20.85	26.05	21.25	24.69	29.78	25.8	5.72	5.06	5.14	5.21	5.28
20-30kt	11.94	14.26	13.59	12.13	11.62	7.07	7.69	7.24	8.81	6.95	4.77	4.3	4.37	4.64	4.4
30-45kt	7.93	7.81	7.87	7.88	7.41	4.23	6.52	4.71	4.81	4.1	9.16	9.48	9.31	10.43	8.31
45-60kt	4.82	4.74	4.87	4.63	4.37	0.69	1.01	0.77	1.03	0.66	3.58	4.12	4.01	4.71	3.21
60-80kt	6.91	7.96	7.71	6.61	6.41	1.07	1.38	1.13	1.11	1.03	9.71	11.81	11.26	12.42	8.87
> 80kt	5.22	6.64	6.31	5.75	4.97	1.26	2.09	1.58	1.85	1.34	18.2	24.44	22.65	24.36	16.62
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

As shown in previous charts and Table 4, the differences in emissions between port results may relate, among others, to differences in port specialization (major or minor role of the different sub- sectors) and the classification of vessels sizes. Ideally, information by subsector, pollutants and size should be obtained in order to have a detailed view on vessel traffic in each harbour area. This information is unfortunately not available for all subsectors but it is in the case of passenger vessels. This enables a more detailed study. Thus, to better understand passenger subsector and its emission profile, detailed results of exhaust pollutants by sizes are presented below. As mentioned before, and in order to achieve more refined comparisons among ports, results of emissions have only been accounted from manoeuvring and berthing vessels sailing to a speed equal or below 5 knots. In this way, potential differences among ports due to differences in the fairway channel are avoided (see Section 3 for further explanations).

In terms of the operative time (activity[19]) of passenger vessels hotelling and manoeuvring in the harbour areas, 66,089 hours are accounted in total from which a 46% (30,765 hours) relate to St. Petersburg, a 36% (23,657 hours) to Las Palmas and an 18% (11,667 hours) to Hong Kong. As expected, when observing activity levels in the three harbours the major share is of hotelling hours. Specifically, a 99% in the ports of St. Petersburg and Hong Kong and a 97% in the port of Las Palmas. When compared to the rest (see Table 5 at the end of this section) a minor percentage share of hotelling hours in Las Palmas Port may be due to the percentage weight of manoeuvring hours accounted by ferry

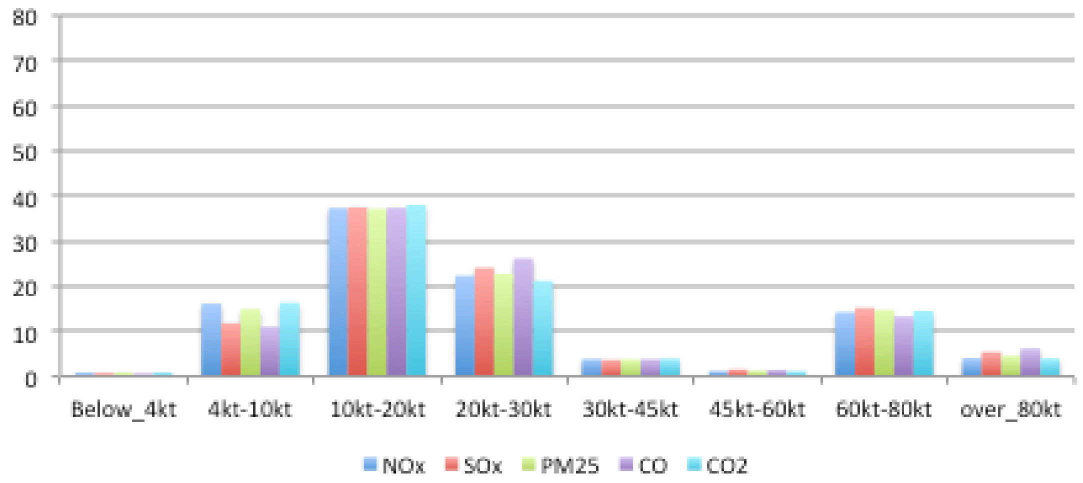
[18] To facilitate comparisons a graphical representation by port (Figure 1A, 2A and 3A) has been included in the Appendix.

[19] Although additional parameters can be used as an indicator of vessel activity (port calls/ in port distance travelled), the authors of this paper have decided to use AIS-based hours per operative type. The latter since the available port call details do not include the duration of the port call (this would require additional processing). Also, since the distance travelled in port (km) does not represent the activity of berthing (hotelling) ships.

vessels. Also, to operative profiles of passenger vessels already identified in this harbour (Tichavska and Tovar, 2015a).

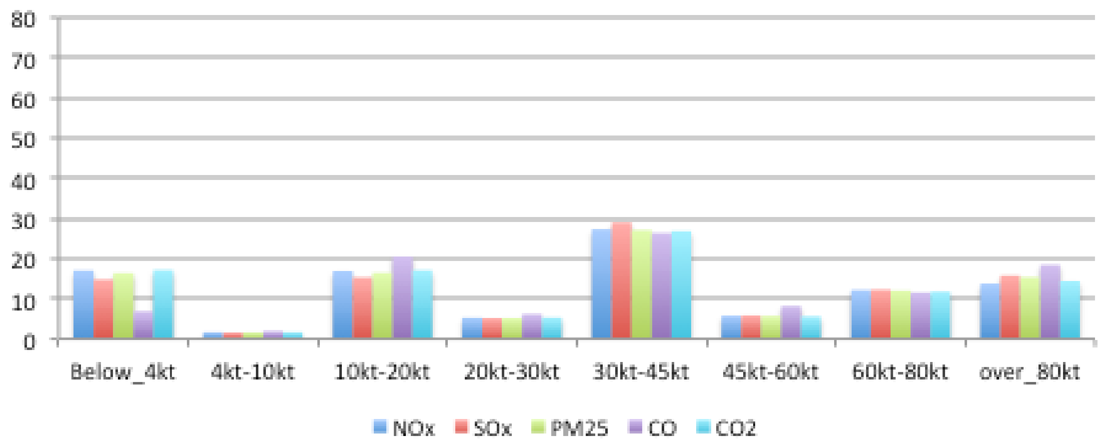
In addition to the activity level, which we analyse with detail below, differences among results of ship types may also derive from the combinations of size classes, which largely differ over ports, as shown in the following figures.

Figure 6 – Emission results by size classes of passenger vessels hotelling and manoeuvring in the port of Las Palmas (2011)



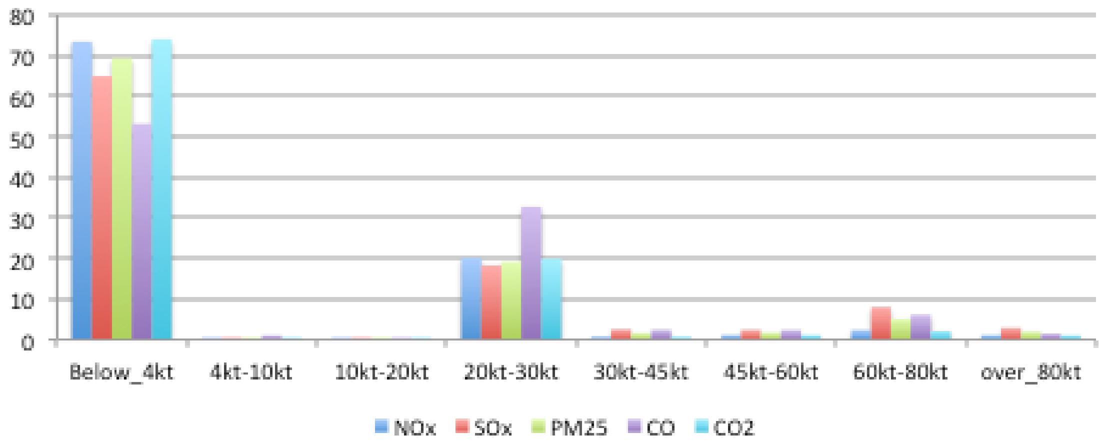
For instance, the emission contribution of passenger vessel sizes in Las Palmas port (Figure 6) mostly allocate from 4,000 tons to 30,000 tons and from 60,000 tons to 80,000 tons, while in St. Petersburg (Figure 7) the representative shares belong mostly to the small and medium sizes.

Figure 7 – Emission results by size classes of passenger vessels hotelling and manoeuvring in the port of St. Petersburg (2011)



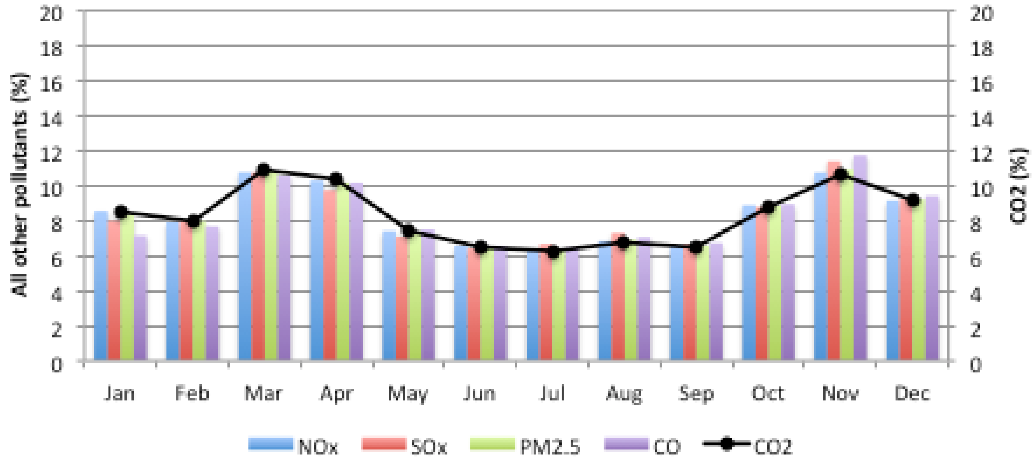
In Hong Kong (Figure 8), most of passenger emissions allocate in the smallest (below 4,000 tons) and the medium size of categories (from 20,000 tons to 30,000 tons).

Figure 8 – Emission results by size classes of passenger vessels hotelling and manoeuvring in the port of Hong Kong (2012)



In the case of passenger vessels, the temporal variation has also been addressed. The monthly (seasonal) character of the cruise and ferry business largely depends on the geographical location and the weather trends. Ports located closer to polar regions (lower temperatures), will be for instance more affected by seasonality than those located near the equator (experiencing milder climates). In any case, months within holiday season will see the cruise and ferry business peaking and, this seasonality represents infrastructure, service, and port-city challenges for the people living in the surroundings and who´s business depend on the activity of the port (ESPO, 2016). The latter motivates the importance of understanding the temporality of results, as this allows to align corrective or contingency measures (when necessary). As we will see in the following figures and in some cases (Las Palmas), peaks tend to compensate (see Figure 9). In others (St. Petersburg), these tend to intensify (see Figure 10).

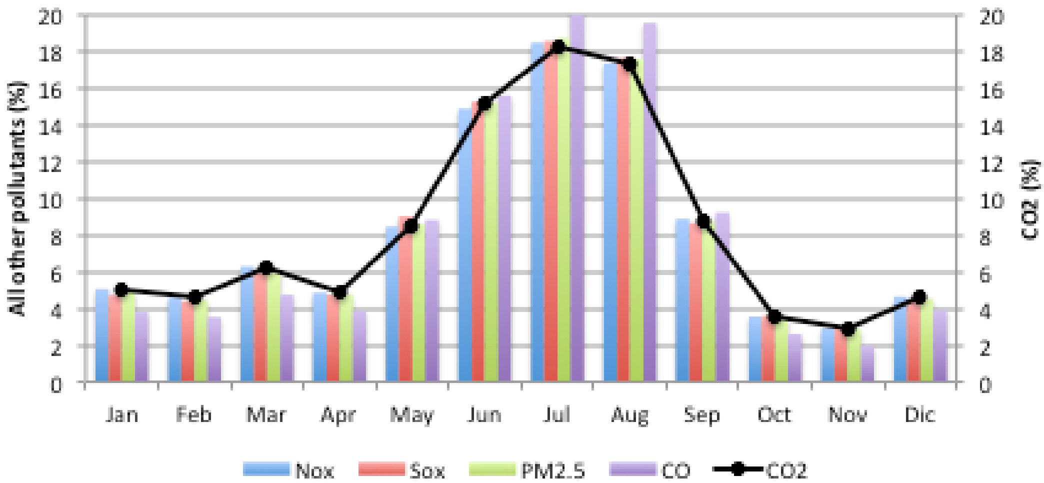
Figure 9 – Monthly emissions from passenger vessels hotelling and manoeuvring in Las Palmas Port (2011)



Monthly emissions derived from passenger vessels hotelling and manoeuvring in Las Palmas Port are presented Figure 9. Results reflect a monthly variation of emissions that is relatively stable over time with the highest peaks allocated in March, April, November and December. The latter is consistent with the seasonal distribution of ferry services that commonly operate all year long over regional routes with holiday peaks in summer and, cruise vessels mostly calling this port during the first and the last quarter of the year (EDEI, 2011).

Temporal differences when addressing St. Petersburg are noticeable (see Figure 10). This is due to the fact that most of the vessel activity allocates in summer. Indeed, there is only one all-year-round Ro-Pax ferry operator (St. PeterLine) in St. Petersburg port, whereas major cruise activities commence during summer navigation that starts in early May and ends in mid-late October. During the winter is the tourist low season and the ice conditions in the harbour prevent non-winterized ships from safe operations resulting in a seasonal reduction of passenger vessel traffic.

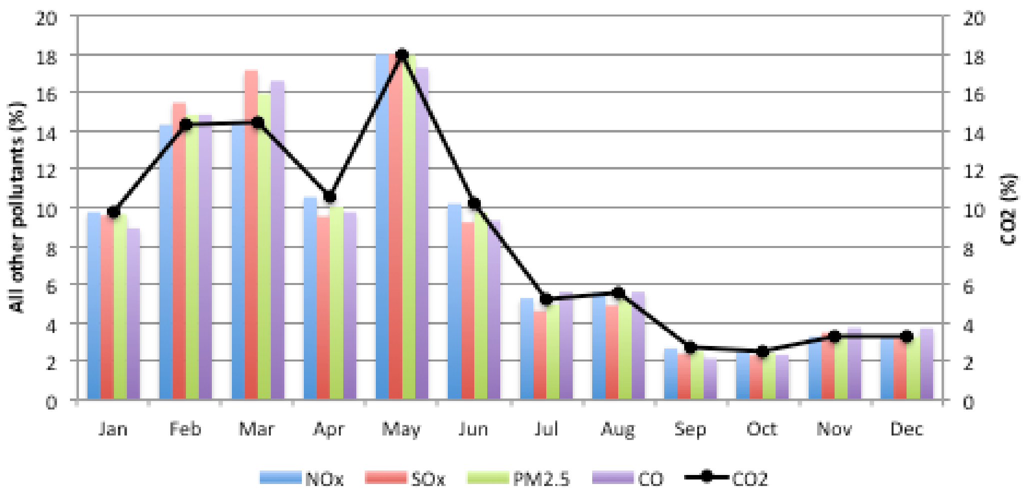
Figure 10 – Monthly emissions from passenger vessels hotelling and manoeuvring in the port of St. Petersburg (2011)



Monthly emissions derived from passenger vessels in the Port of Hong Kong are presented in Figure 11. Results reflect a temporal variation with a positive growth from January to March and the highest peaks in February, March and May. Although emission results from the first quarter of the year are apparently consistent with the statistical growth of activity accounted with passenger port calls (Marine Department, 2012) temporal interpretation should be addressed with care. Particularly, within the peak season from October to late January or early February where vessel traffic flows are commonly high but different to our results, which reflect a temporal reduction in similar periods. This may be due among others to temporality gaps on the AIS[20].

Seasonality affects cruise and ferry operations differently. Therefore, temporal profiles of passenger vessels could compensate differences between cruises and ferries, as occur in Las Palmas port case, or reinforce the peak emissions as happen in San Petersburg port. For this reason, they could have been reflected in a better way if represented alone. Although, unfortunately, monthly emission results are not available by passenger subsectors (cruise and ferry), Table 5 presents emission results and operative hours (hotelling and manoeuvring) by ferry and cruise vessels. This is of great interest since operative profiles are diverse when compared to each other. For instance, in the referred harbour areas, cruise vessels accounted more time in hotelling than ferries while on the other hand ferries accounted more time manoeuvring than cruise vessels.

Figure 11. - Monthly emissions from passenger vessels hotelling and manoeuvring in the port of Hong Kong (2012)



According to results and in terms of pollutants that associate to local effects (NOx, SOx, $PM_{2.5}$. and CO) the role of ferry vessels is the most representative in the port of Las Palmas with a 70% from the passenger category while the role of cruise prevails in St. Petersburg and Hong Kong reflecting a 62% and an 87% respectively, from its port totals. Similarly, when addressing emission results for CO_2, ferries maintain the largest share in Las Palmas Port with a 69% while cruise vessels domain the estimated tons in St. Petersburg and Hong Kong with a 62% and an 86% respectively.

As expected, a direct relation of the highest exhaust emissions to the operative hours in harbour (activity level) can be observed). For instance, the large emission contribution of ferry vessels in Las Palmas Port directly relate to the share of operative hours in hotelling (83% from the passenger total) and manoeuvring (85%). This is different to St. Petersburg and Hong Kong where the largest emission share is obtained from cruise vessels which are also representative mostly, in terms of operative hours in hotelling (59% in St. Petersburg and 61% in Hong Kong).

[20] AIS transmissions have a limited coverage range across the surface of the Earth. Thus, the granularity of AIS data recorded by terrestrial stations depends on the number of active stations and where these are located.

Table 5 – Exhaust emissions from cruise and ferry vessels hotelling and manoeuvring in the ports of Las Palmas, St. Petersburg and Hong Kong.

	Pollutants (Ton)					Activity level (hours)	
LPA	**NOx**	**SOx**	**$PM_{2.5}$**	**CO**	**CO_2**	**Hot**	**Man**
Cruise	102	5	4	8	5.721	3.833	92
Ferry	236	11	9	19	12.961	19.209	524
Total	338	16	13	27	18.681	23.042	616
STP	**NOx**	**SOx**	**$PM_{2.5}$**	**CO**	**CO_2**	**Hot**	**Man**
Cruise	366	14	13	28	20.691	17.877	114
Ferry	228	9	8	15	12.826	12.539	235
Total	593	22	21	43	33.517	30.416	349
HK	**NOx**	**SOx**	**$PM_{2.5}$**	**CO**	**CO_2**	**Hot**	**Man**
Cruise	124	30	8	9	6.899	7.085	126
Ferry	20	3	1	1	1.115	4.444	12
Total	144	33	9	10	8.014	11.529	138

To summarize and in terms of a specific valuation of SOx and $PM_{2.5}$ among the three ports it can be observed that in despite of a reduced level of activity (a 39% from the activity hours of St. Petersburg and a 23% from Las Palmas) and when compared to the other two ports, Hong Kong reflects SOx emissions that are considerably higher (+50% if compared to St. Petersburg and a +100% if compared to Las Palmas). Regardless of differences in the fleet size and configuration, results obtained suggest that this is mainly due to the regulation in force in the three ports reflected in the STEAM model. On the other hand, and when comparing St. Petersburg with Las Palmas we find that despite accounting a lower activity level (59% of the activity hours in Las Palmas) St. Petersburg reflects higher emission shares of every pollutant (from +59% to +79%) including SOx although the percentage variation of the later is the smallest one (+38%).

In terms of sub-sectors within passenger shipping and in the case of cruise, Las Palmas accounts a 73% from the activity hours of St. Petersburg and only a 36% from the emissions of SOx. In other words, St. Petersburg accounts 1.38 times the activity level in Las Palmas and yet multiplies over three times (2.8 times in the case of SOx) its emission results. In terms of ferries, Las Palmas accounts 2.19 the activity hours from St. Petersburg but reflects only +1.22 times more of SOx and with a 46% from the activity level of Las Palmas, St. Petersburg accounts an 82% of its SOx share.

5. DISCUSSION AND POLICY RECOMMENDATIONS

Comprehensive emission inventories built from AIS vessel tracks, serve as the first of steps to address the atmospheric dispersion of pollutants, the related exposure assessment, impact modelling and its internalization through the estimation of the externality costs. Moreover, the estimated results represent a baseline externality scenario to address future measures that reduce the local and global impacts of vessel emissions.

Indeed, the transformative character of scientific knowledge for policy making has been acknowledged for more than four centuries (Bacon, 1625). Given that most policy making is ideally based on a weighing of risks and benefits and aims to deliver equilibrium outcomes for all involved parties, scientific contribution, even imperfect or incomplete, is desirable when new policies are drafted. Since the 1990´s when problems of air emission from shipping were first addressed in policy-making, regulation has been based on estimation models, which did not allow disaggregating emissions neither by vessel particularities nor, by type of operations. For instance, widely used in the United States activity-based emission inventory is based upon survey-derived activity data complemented by ship database and estimated emission factors (WPCI 2014). In respect to previous estimation methods, integration of AIS data into the STEAM enables a comprehensive approach, overall since it allows identifying fleet differences and polluting profiles over vessel size, type, and time spent during different operative modes.

The results presented in this paper exemplify how the disaggregation of emission inventory can provide policy support. They show that whereas three investigated ports (Las Palmas, St. Petersburg and Hong Kong) are situated within different regulatory frameworks, which yield different requirements for sulphur content in fuel, the emission patterns cannot be explained solely by regulatory differences. Disaggregated results of STEAM-based inventory draw attention to other factors than sulphur content in fuel, which impact the amount of air emissions from vessels in ports. For instance, they highlight that hotelling navigation constitutes a significant source of emissions, and this mode of operation is pronounced for berthing cruise vessels.

The emergence of new emission estimation technology allows regulators to "look outside of the box", shifting the classical regulatory governance problem of striking a balance between implementation and compliance towards searching for new regulatory solutions. On the one hand, contemporary policies may require an update in terms of scope (what is to be regulated) and extent (how much/stringent are the issues to be regulated). On the other hand, the 'one-size-fits-all' approaches of existing regulation, which does not foresee specific provisions for different segments of shipping, can be challenged. Estimation of emissions with integration of vessel-specific data can help achieving most targeted regulatory solutions for each segment and/or type of operation.

Finally, the regulatory mechanisms which are activated to limit the air emissions from ships, such as monitoring, certification, control and penalization, as well as service-provision, rely on multiple actors including ship owners, ports, bunker suppliers, authorities and others. A detailed understanding of a connecting relation between regulatory frameworks and air emissions will help including all related stakeholders at relevant stages of emission mitigation process. Indeed, in the light of the evolving understanding on emission impacts from shipping, a robust ship-specific system for monitoring, reporting and verification (MRV[21]) of emissions that is based on fuel consumed on port-to-port voyages has been recently addressed by the EU (EU/2015/757).

It is expected that the EU MRV system will serve as a model of implementation for a global MRV. According to EU EU/2015/757 guidelines, if an agreement on a global MRV system is to be reached, the Commission should review the Union MRV system with a view to aligning it to the global MRV system.

Finally, based on the analysis of the case-study material in the light of regulation and go

[21] The MRV requires ship owners and operators to annually monitor, report and verify CO_2 emissions for vessels larger than 5,000 GT and which call at any EU port. The results will be published on a regular basis. Entered into force on 1 July 2015, the regulation will become fully effective on 1 January 2018. Shipping companies will need to prepare a monitoring plan by 31 August 2017 at the latest for each of their ships that falls under the jurisdiction of the regulation. They will have to monitor and report the verified amount of CO2 emitted by their vessels on voyages to, from and between EU ports and will also be required to provide information on energy efficiency parameters.

vernance framework, the following recommendations can be provided:

- Diversify the type of regulation in terms of their scope. Whereas type of fuel and its sulphur content is important, these are not the only factors, which determine the levels of air pollution in ports. Hotelling mode of operation has a significant impact on the amount of pollutants emitted. Thus its impact should be minimised. For instance, new policy can incentivize or even oblige ports to enable the use of shore-side electricity and ship-owners to use it (especially if they stay at berth for long periods in time). Also manoeuvring operations shall be optimised in order to cut emissions. New policies could address port design and efficient operations, e.g. through the possible use and strategic location of automated mooring systems that can reduce operative time when approaching the quay. In fact, automated mooring systems, performing with vacuum technology that can pull the vessel towards the quay and keep it steady, allow engines to be shut off approximately half an hour earlier. Also, mooring operation times can be reduced to a few seconds only. Still, automated mooring systems may be a costly and custom solution. Also its wider use may be limited by operational characteristics of each port.
- Specify regulation in terms of their target. Whereas different types of ships have different fuel requirements and operation patterns in ports, current regulation does not make enough difference between shipping segments and pollution regulation. New policies can address air emissions more effectively if different segments would be specifically addressed. This would allow a better design of abatement policies. For instance, in relation to the use of cold ironing by segments with the highest hoteling times and pollution shares. Also, this would allow to improve the accountability of subsector´s responsibility over emissions (i.e. the Polluter Pays Principle could be better applied). The latter is in line with the proposal made by Kågeson, (2009) which considers an en-route charging or tradeable credit scheme system where fees for pollutants abatement are based on the distance and time travelled.

Future research may include include air quality and health impact studies. Recently, Soares et al., (2014) presented a similar study for Helsinki metropolitan area, which represents a case study for an EU port inside a Baltic Sea SECA and exemplifies the full chain of impact studies starting from emissions to impacts on human health. Our current study for three port cities does not yet include the impact component, but it is a first step on this approach.

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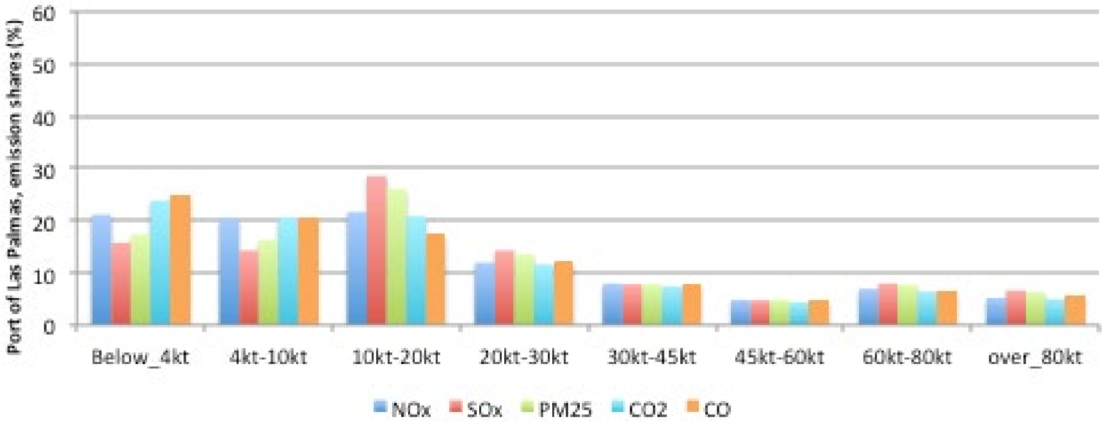
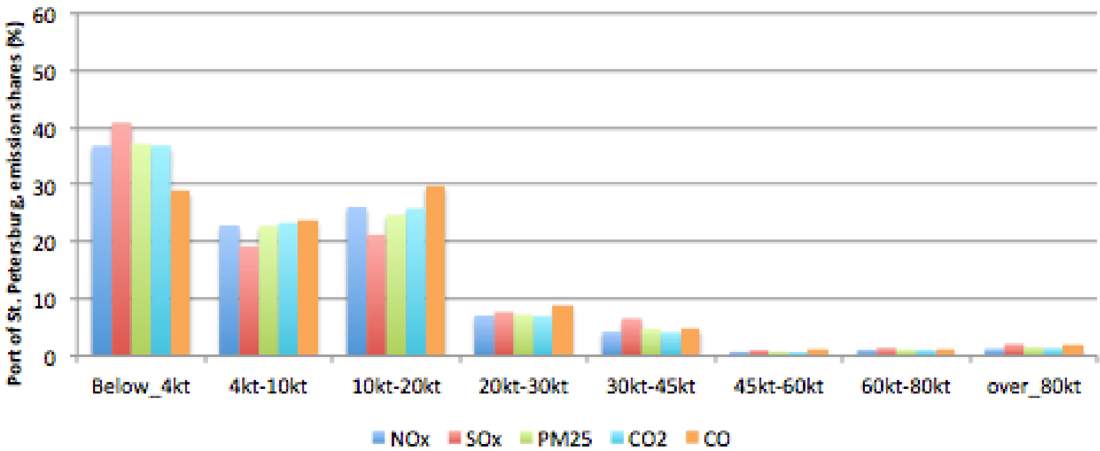
APPENDIX

Figure 1A – Emission results by size classes in Las Palmas Port (2011)



In Las Palmas Port (Figure 1A), the three highest emitting size class of vessels in relation to every pollutant remain in the small and medium sizes, below 20,000 tons. The same size classes remain as the ones with the largest shares in St. Petersburg (Figure 2A) but with higher percentages from the totals at port, meaning that the vessels in the three largest size categories have less prominence than in the other two harbours.

Figure 2A – Emission results by size classes in the port of St. Petersburg (2011)



In the port of Hong Kong (Figure 3A) the top three emission shares from size categories remain the same over gases but are considerably different from Las Palmas and St. Petersburg. Indeed, while in the later two ports the major share exclusively relates to tonnage below 20,000 tons, the largest size classes play an important role in Hong Kong. Indeed, it can be observed that percentage share of vessels over 60,000 tons represent between a 25% and a 37% from the totals whereas in the other two harbours these never represent over a 15% (Las Palmas) or a 3% (St. Petersburg). Regarding other size categories and in the case of Hong Kong, size class below 4,000 tons is the largest representing an overall contribution between a 38% and a 50% from the total port share. Moreover, and also in Hong Kong, overall results of GT between 4,000 tons and 60,000 tons do not exceed a 10% per pollutant from the port totals.

Figure 3A – Emission results by size classes in the port of Hong Kong (2012)